EVALUATION OF A PORTABLE HELICOPTER OXYGEN DELIVERY SYSTEM

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ABSTRACT

Rotary-wing aircrew can be repeatedly exposed to moderately high altitude (up to 18,000 feet pressure altitude), making hypoxia and its performance effects a real hazard. Accordingly, USAARL was tasked to evaluate a portable oxygen system for potential use by U.S. Army helicopter aircrew. The system described below provided capability for oxygen production, charging of the portable system, as well as final use by aircrew. The objectives of the investigation were to determine if the system can adequately protect aircrew from hypoxia at altitude, to assess the integration of the device into existing Aviation Life Support Equipment (ALSE), and to verify ease of use.

Eighteen subjects were exposed to altitudes of 10, 15, and 18 thousand feet with and without exercise. Throughout the study, the subjects' SpO_2 (peripheral hemoglobin oxygen saturation) was continuously monitored. Two criterion values were selected: 91%, above which no cognitive deficit is expected, and 80%, below which significant cognitive deficits are more frequent.

Mean SpO_2 declined significantly with increasing altitude whether the subjects were on or off oxygen. With the oxygen system in use (nasal cannula), mean SpO_2 levels were above 91%, significantly better than without supplemental oxygen. Post exercise SpO_2 was significantly lower ($p<0.001$, paired t-test) than pre-exercise for both mask and cannula conditions.

The system provided adequate oxygenation (defined as SpO_2 >91%) at low levels of exertion up to 18,000 feet, but oxygenation dropped with exercise at the higher altitudes. These findings supported recommendations to the customer for operational use and further research.

1. INTRODUCTION

Current U.S. Army operations are exposing rotary wing aircrew to repeated incidences of moderately higher altitudes (up to 18,000 feet pressure altitude). The current flight regulations (AR 95-1) list the following requirements for flight at altitude:

"Approved oxygen systems will be used as follows:

Unpressurized Aircraft.

Oxygen will be used by aircraft crews and occupants for flights as shown below:

(1) Aircraft crews.
   (a) On flights above 10,000 feet pressure altitude for more than 1 hour.
   (b) On flights above 12,000 feet pressure altitude for more than 30 minutes.

(2) Aircraft crews and all other occupants.
   (a) On flights above 14,000 feet pressure altitude for any period of time.

   (b) For flights above 18,000 feet pressure altitude, oxygen pre-breathing will be accomplished by aircrew members. Pre-breathing may utilize either 100 percent gaseous aviator's oxygen from a high pressure source, or an onboard oxygen generating system (OBOGS) that supplies at least 90 percent oxygen in the inspired gas. Pre-breathing will be for not less than 30 minutes at ground level and will continue while en route to altitude. In those extraordinary cases where mission requirements dictate rapid ascent, commanders may authorize shorter pre-breathing times on a case-by-case basis, with the realization that such practice increases the risk for developing altitude decompression illness. Return to normal oxygen (pressure demand regulator, gaseous oxygen-equipped aircraft) is authorized on descent below 18,000 feet pressure altitude, provided continued flight will not exceed this altitude."

In-theater operations involving AH-64, MH-60, and OH-58 aircraft are currently utilizing a non-proven portable oxygen system and are subject to hazard as a result. These aircraft types have significant weight and

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space limitations which preclude the use of oxygen concentrator or heavy cylinder systems.

Referring to the oxygen dissociation curve, the figure of 80% SpO_2 which refers to an adequate partial Pressure of Arterial Blood Oxygen (PaO_2) (Pickard, 2002) is accepted as the level where tissue oxygen perfusion can begin to be compromised and the effectiveness of the system was assessed against this benchmark. In a similar study, Joshi and Thakur (2004) selected 65% SpO_2 safety cut off when they exposed aircrew up to 21,000 ft in an altitude chamber with no reported adverse events.

Military Relevance

Given the current and possibly future theaters of operation for Army Aviation, there is an immediate need for a safe and effective portable oxygen delivery system for aircrew. There has been a request from both field aviation units and PM Air Warrior for USAARL to evaluate the system under study.

2. OBJECTIVES

The aim of this study was to measure the effectiveness of the Aqualung® Portable Helicopter Oxygen Delivery System (PHODS) in ameliorating the effects on rotary aircrew to moderate altitude exposure.

Specific objectives were to test whether the system provided adequate oxygenation (higher than 80% SpO_2) at rest (simulating the pilot role) and during moderate exercise (simulating the crew chief/gunner role).

USAARL was tasked by Project Manager Air Warrior to test a portable oxygen system with specific emphasis on possible use by Army Aviation in current operations. The system tested was complete in that it provided for all areas from oxygen production through portable system charging to final use by aircrew

3. METHOD

One portable oxygen system was evaluated during this study: Aqualung® Helicopter Oxygen Delivery System. This system is man-mounted (Fig. 1) and delivers oxygen from a standard and portable aluminum Survival Egress Air (SEA) bottle (located on the survival vest) via nasal cannula to the aircrew member.

A unique feature of this apparatus is the inclusion of a MH EDS 02D1 Pulse Demand Oxygen Unit (Fig. 2), which according to the manufacturer (Mountain High® Corp.) automatically provides "on-demand" oxygen regulated to altitude by detected barometric pressure (pressure altitude), which is unlike the system presently used by aircrew. Other features of the regulator include algorithms to detect and react to the aviator's breathing patterns.

Figure 1. Aqualung PHODS in typical aviation configuration.

Figure 2. MH EDS O2D1 Pulse Demand Oxygen Control Unit.

The oxygen used was produced by the Breathing Air Systems Mobile Oxygen Concentrator (Mobile O_2), and the portable bottles were charged with the Deployable

Oxygen Charging System – Oxygen (DCS-O) by the same company (Fig. 3). These equipments are FDA certified and are currently field deployed with U.S. Forces.

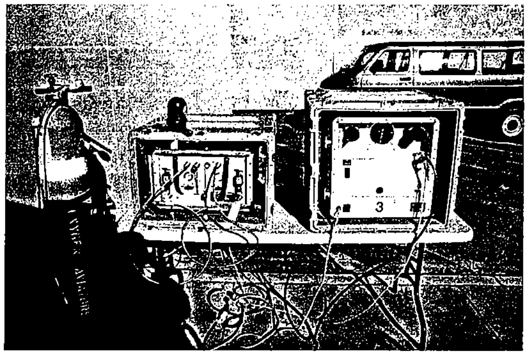

Figure 3. Oxygen Generator and charging system

There are several aspects of airworthiness such as environmental hazards, human factors, and aircraft integration that were not addressed by this study; some of which will be addressed in a separate study by the Airworthiness Certification Branch of USAARL. The purpose of the current investigation was to determine if the system adequately protects the aircrew member from hypoxia at altitude and to determine its ease of use by aircrew.

Subjects acted as their own controls in the study and all were exposed to altitudes of 10, 15, and 18 thousand feet in four conditions:

- Sitting still off oxygen simulating radio calls
- Sitting still using the system simulating radio calls

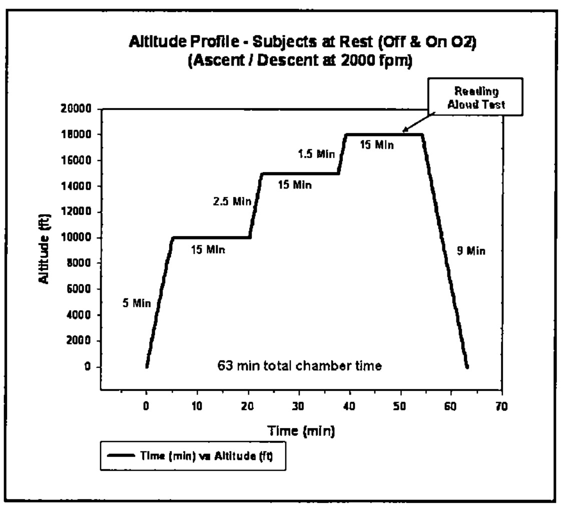

Figure 4. Chamber profile for the at rest testing

- Exercising using the system with nasal cannula
- Exercising using the system with a face mask

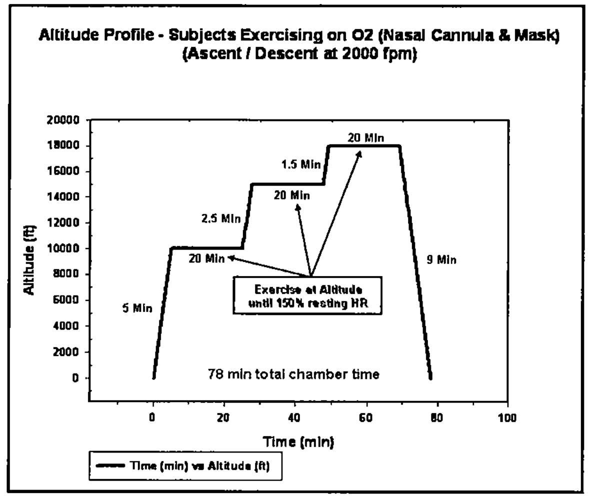

Figure 5. Chamber profile for the exercise testing

Throughout the study, the subjects SPO_2 (Peripheral oxygen saturation) was monitored with the critical values being 91% (DeHart and Davis), the value most usually associated in the medical literature with no cognitive deficit, and 80% below which the subjects were not allowed to go to minimize risk.

The subjects were also tested throughout the study on a color-vision anomaloscope. This device detects subtle changes in color vision, which have been shown to be a good early indicator of relative hypoxia to the brain. (Vingrys, A.L. and Garner, L.F, 1987)

4. INTEGRATION ISSUES

The portable helicopter oxygen delivery system (PHODS) had an absolute requirement to fully integrate with all of the other life support equipment worn by the Army Aviator, the major components of this equipment being the helmet and the Air-Save or Air Warrior survival vests. The nasal cannula required a bracket to be attached to the right hand side of the HGU-56P helmet (Fig. 1), and the mask was designed to utilize the mounting brackets for the maxillo-facial shield. The oxygen supply bottle was designed to fit the pouch that is normally occupied by the survival egress air (SEA) bottle, and if there is a requirement for both bottles then a further compatible pouch has been produced. Finally, the routing and nature of the oxygen tubing has been determined in concert with the ALSE experts at USAARL to ensure there is a minimal snagging hazard and a low risk of kinking the tubing and compromising supply.

5. RESULTS

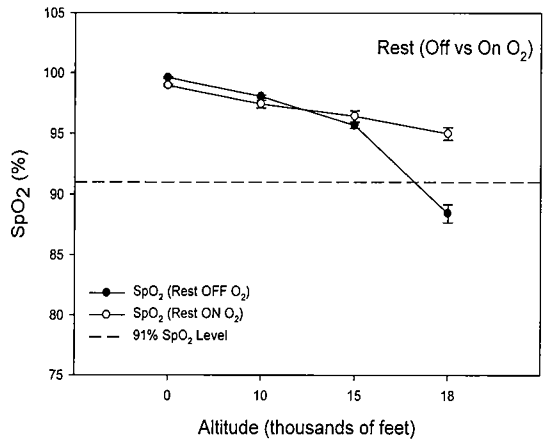

Figure 6. SpO_2 vs Altitude for subjects at rest on and off oxygen

There was a significant decrease in SpO_2 ($p<0.05$, Chi-square testing) with increasing altitude at rest on and off oxygen. Off oxygen this decrease is physiologically significant in that it reduces oxygenation below the 91% level (Fig. 6). With the oxygen system in use (nasal cannula), this reduction did not fall below the 91% level and oxygenation was significantly better ($p<0.001$, paired T-test) than without oxygen.

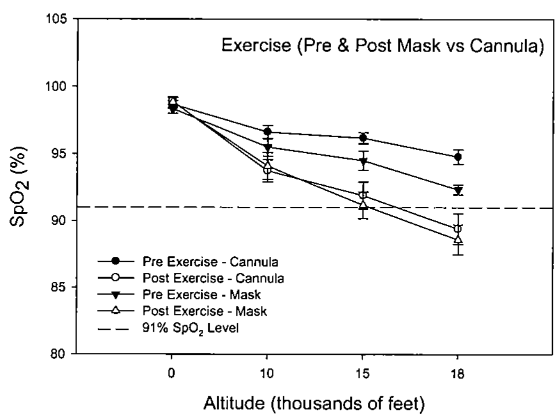

Figure 7. SpO_2 vs Altitude for subjects exercising on oxygen using cannula or mask

Post exercise SpO_2 was significantly lower ($p<0.001$, paired T-test) than pre-exercise for both mask and cannula conditions (Fig. 7). There was no significant difference ($p>0.05$, T-test) in SpO2 between mask and cannula after exercise (Fig. 7).

Subject opinions on the usability of the system were generally positive with some reservations on both the mask and nasal cannula. These were not consistent across the subject group, and the detail has been fed back to the manufacturers

6. DISCUSSION

The broadly accepted physiological limit of 91% SpO_2 above which there is no significant cognitive impairment was largely reached by subjects using the system under test.

The PHODS maintained hemoglobin saturation above 91% at rest (Fig. 6) and during simulated pilot tasks (radio calls). This would provide protection from the negative effects of altitudes up to 18,000 feet. The system, however, did not maintain the 91% level during moderate exercise above 15,000' (Fig. 7) using either mask or nasal cannula. Furthermore, contrary to the author's expectations there was no perceptible difference in effectiveness of oxygen delivery between the mask and nasal cannula.

There is a definite training need associated with the use of the PHODS; while using the nasal cannula, the user must breathe through the nose. Although this may seem completely self-evident, it had to be reinforced during the course of the study, especially when moderate exercise was performed.

Anomaloscope color vision testing did not reveal any significant change from baseline in any condition. This was not unexpected as subjects were not allowed to dip below 80% SpO_2 during the study, a level where cognitive effects are not expected to be prominent.

Another caveat that must be added was that no subjects were female; the authors do not anticipate any gender effect, but this was not tested.

CONCLUSION

The authors believe that the PHODS system is capable of maintaining the SpO_2 of properly trained Army Aviators up to 18,000' PA. However, care must be taken with exertion by aircrew members above 15,000' PA.

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